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Provisional Application Cover Sheet

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INVENTOR(s)/APPLICANT(s)

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Aubrey	Leonard, S.	Hendersonville, NC

TITLE OF THE INVENTION

MEMORANDUM OF INVENTION COVERING MICRO-POROUS MEDIA DEGASSER

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ENCLOSED APPLICATION PARTS (check all that apply)

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By Carla Arnette
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Respectfully submitted,

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Memorandum of Invention
Micro-Porous Media Degasser
Leonard S. Aubrey
June 3, 2003

Memorandum of Invention Covering Micro-Porous Media Degasser

Background

Hydrogen is the only gas with significant solubility in molten aluminum. Figure 1 shows the solubility of hydrogen in pure aluminum as a function of temperature. Figure 1 shows that as the temperature of molten aluminum decreases to the solidification temperature, there is a sudden sharp drop in hydrogen solubility. This sharp drop in solubility results in the formation of undesirable micro-shrinkage and porosity in the final solidification structure. Figure 1 shows that only about 5% of the dissolved hydrogen present in the molten aluminum remains after completion of solidification. The remaining 95% is rejected into the liquid until the concentration reaches the point where a hydrogen gas bubble is formed.

Contact of molten aluminum with water moisture in the air during melting, transfer, and casting is nearly ~~avoidable~~ unavoidable. Molten aluminum is highly reactive and can easily reduce or decompose any water moisture present by the following reaction:

$$H_2O\ (g) + 2/3Al\ (l) \Rightarrow 1/3Al_2O_3\ (s) + 2\underline{H}\ (in\ Al)$$

The removal of hydrogen down to an acceptable level prior solidification is required to obtain a metallurgically sound ingot or casting. The industry accepted practice to remove or lower the dissolved hydrogen content is to bubble an inert or semi-inert purging gas directly through the molten aluminum prior to casting and solidification Figure 2 shows that dissolved hydrogen in molten aluminum exhibits a high vapor pressure relative to common alloying constituents and other impurities. Hydrogen therefore can be removed preferentially either by inert gas purging or vacuum treatment. Hydrogen dissolved in the molten aluminum is removed by the following reaction:

$$\underline{H}^{+} = 1/2H_2(gas)$$

The chemical equilibrium (K_{H2}) of the above reaction is given by:

$$K_{H2} = \rho_{H2}^{(1/2)}$$

For pure molten aluminum K_{H2} is given by:

$$Ln(K_H) = 5869/T + 3.282$$

There are several ways of directly introducing purging gas into molten aluminum in order to reduce the hydrogen content. The most common methods include using a simple pipe or lance (not very efficient), porous plug (Figure 3), a spinning nozzle degasser (Figures 4 and 5), and high-pressure nozzle injection (Figure 6). The rate of removal and the final hydrogen value obtained is dependent on several parameters such as the metal temperature, thermodynamic solubility, purging gas flow rate, metal flow rate (continuous degassing), furnace size (static degassing), gas removal ratio, and bubble size (surface area). For a given purging gas flow rate the hydrogen removal rate is controlled by the bubble size. The finer the bubble size the higher the rate of hydrogen removal. A simple lance or tube produces a very large bubble size and therefore results in a relative slow removal rate. The removal rate is improved by introducing the gas through a porous plug or by a spinning rotor that chops/shears the gas stream into fine bubbles. The finer bubble size results in increased contact surface area (increase transfer rate) and a slower bubble ascent rate (smaller Stoke's diameter).

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There are several limitations in using inert gas bubbles to remove hydrogen from molten aluminum. Efficient removal requires the gas bubbles to be relatively small in order to maximize contact surface area. The smallest gas bubbles are typically obtained with a rotary impeller degasser (Figures 4 and 5). These degassers are capable of producing very fine bubbles that can remain suspended for a long period of time. As a result rotary impeller degassers are normally installed relatively far (distance-wise) from the casting machine in order to allow sufficient time for gas bubble separation by flotation. This distance from the casting machine provides ample opportunity (time) for re-absorption of hydrogen back into the molten aluminum from atmospheric moisture as well as moisture containing refractory contact materials. The lowest achievable hydrogen content is temperature dependent based on the hydrogen solubility-temperature equilibrium. The lower the temperature at which the hydrogen removal process is conducted, the lower the final hydrogen content at solidification. Ideally hydrogen removal should be made just prior to the onset of solidification, which is not compatible with gas purging.

Porous Media Degasser Concept

<u>Concept Overview:</u> The porous media degasser hydrogen consists of a micro-porous plate or panel that is completely submerged into the molten aluminum or any molten metal (steel, copper, iron) to be degassed. Figure 7 shows a schematic illustration of the porous media degasser concept. Attached to the micro-porous plate are two metal tubes whose function is to provide a continuous flow of a purging gas (argon, nitrogen). The purpose of the flowing inert gas is to continuous remove hydrogen that has diffused into the porous plate and reacted to form hydrogen gas. By continuous removing the hydrogen gas a high driving force is maintained for the diffusion of hydrogen cations (H^+) into the porous plate where hydrogen gas (H_2) is formed. An alternative to using a purging gas is to apply a vacuum to the porous panel through one or more the tubes. Either of the techniques (purge gas or vacuum) for removing the hydrogen gas should be effective.

The presence of hydrogen in argon has a significant impact on the thermal conductivity. This change in thermal conductivity can be measured/quantified using a commercial thermal conductivity analyzer. By measuring the purging gas flow rate and the % of hydrogen gas in argon using a thermal conductivity analyzer, the performance of the degasser can be measured in real-time and performance optimized.

<u>Theory:</u> Rather than generate gas bubbles directly in the molten metal, the purge gas is retained (indirect) within a micro-porous plate that is permeable to the flow of the both the purge gas and hydrogen. The structural requirements for the micro-porous plate are:

- The porous material must not be penetrated by the molten aluminum and molten aluminum alloys.
- The porous material must be permeable to both hydrogen gas and the purging gas.

The micro-porous plate microstructure and material are selected such that capillary penetration of the molten aluminum or molten metal into the micro-porous material will not occur. Material factors properties that control capillary penetration are the molten metal surface energy (γ_{ls}), the metal-material contact wetting angle (θ), and the metallostatic head pressure (H_p). The critical metallostatic pressure (H_p) to penetrate a micro-porous material is defined as:

$$H_p = 4\gamma_{ls}\cos\theta/g\rho\phi$$

Where

H_p = Critical pressure for capillary penetration
γ_{ls} = Interfacial surface energy between the porous media and the molten aluminum
θ = Contact wetting angle of molten aluminum on the porous media.
g = Newton's constant
ρ = Liquid metal density
ϕ = Pore opening size of the porous media.

By selecting a micro- porous material with appropriate γ_{ls} and θ values for given molten metal immersion depth (Hp), the micro-porous plate will resist capillary penetration of the molten aluminum, yet will remain permeable to both the hydrogen gas and the purge gas required to remove the hydrogen gas. By constantly removing hydrogen gas that would otherwise buildup in the porous plate with either a purge gas or vacuum, the driving force for hydrogen removal remains high.

Porous Plate Materials: A wide range of porous materials would work. These included:

- Rigidized Vacuum Formed Fiber Boards – These are materials based on aluminum silicate, silica, magnesium silicate or alumina fibers typically bonded with either colloidal silica or alumina. The fiber microstructure is extremely fine and open (60 -70%). These materials have excellent thermal shock resistance due to their discontinuous fiber matrix. Vacuum formed fiber boards have low thermal diffusitivity and therefore have do not chill (freeze) the molten aluminum on initial contact. Commercial rigidized vacuum formed boards are available commercially from either ZIRCAR Ceramics Inc. or RATH Performance Fibers.
- Open Cell Reticulated Ceramic foam – These materials are completely open cell with a discontinuous structure. To prevent metal penetration, a relatively fine pore size (> 60 ppi) would have to be used.
- Ceramic foam with a micro-porous coating.
- Bonded particle materials.
- Ceramic materials where an organic pore former material (walnut flour, organic micro-spheres, saw dust) is added to the slurry that burns out during firing.

Porous Plate Design: Figure 7 schematically illustrates one possible porous plate design. Figure 7 shows a porous plate with two metal tubes attached. The purpose of the metal tubes is to either to introduce and remove the purging gas or for applying a vacuum. Within the porous plate one could introduce internal passageways to improve the distribution of the gas flow and reduce gas pressure drop. The tubes could be constructed out of steel or austenitic stainless steel. To slow or prevent the dissolution of the tubes, a coating could be applied (plasma coated with alumina or zirconia or painted with boron nitride).

Figure 8 shows an alternative design where the porous plate is hollow inside. The advantage of this design is reduced pressure drop since the purge gas is not forced to flow through a porous media.

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Application of Porous Plate: The proposed invention calls for the micro-porous plate to be submerged entirely below the surface of the molten metal. Figures 9 and 10 are schematic illustrations showing a porous plate submerged in a crucible or ladle of molten aluminum. In continuous casting process micro-porous plates could be installed in a wide range of locations depending on the specifics of the casting technology. In the case of billet or ingot casting, the micro-porous plates could be installed in casting launder either before or after the filter bowl (Figures 11 and 12), in the actual filter bowl (Figure 13), or in the actual ingot head (ingot casting). In continuous strip casting the porous plates could be installed in the casting launders, filter bowl, head box or embedded within the casting tip. The micro-porous material could incorporated as part of the actual launder material (Figure 14).

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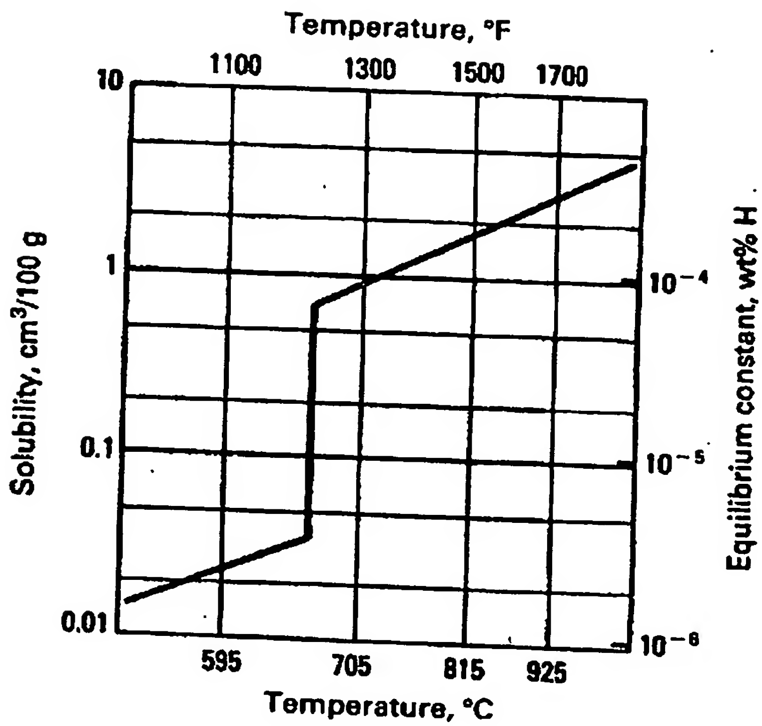

Figure 1: Solubility of hydrogen (one bar pressure) in pure molten aluminum as a function of temperature.

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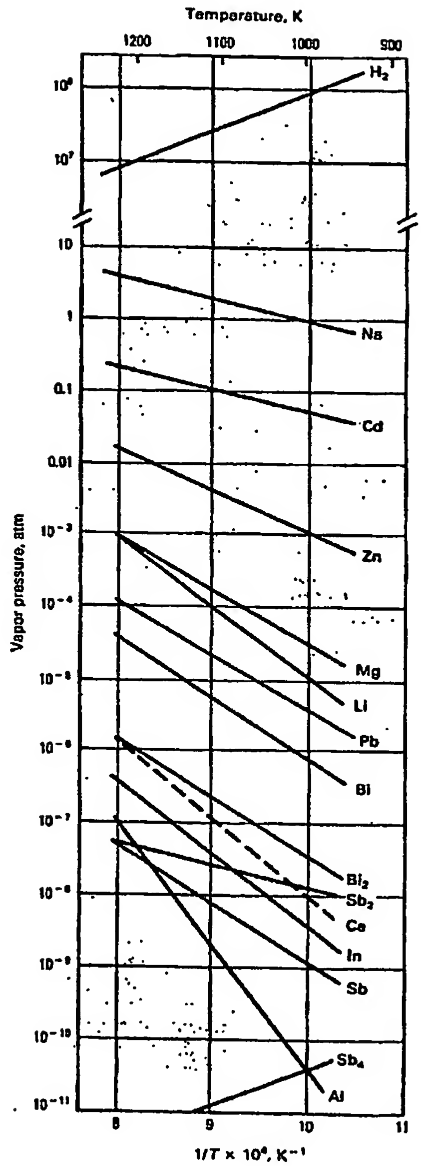

Figure 2: Calculated vapor pressure of selected elements dissolved in molten aluminum at the hypothetical 1 wt. % standard state.

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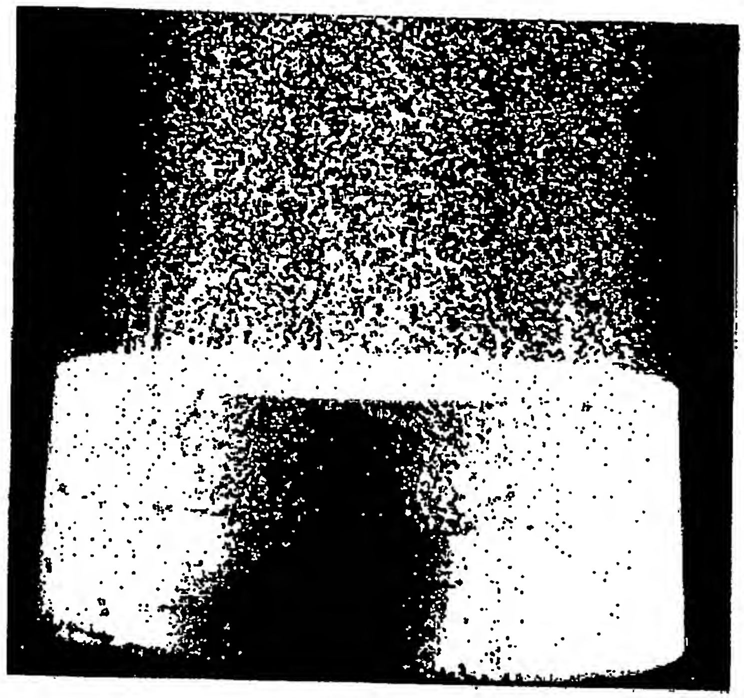

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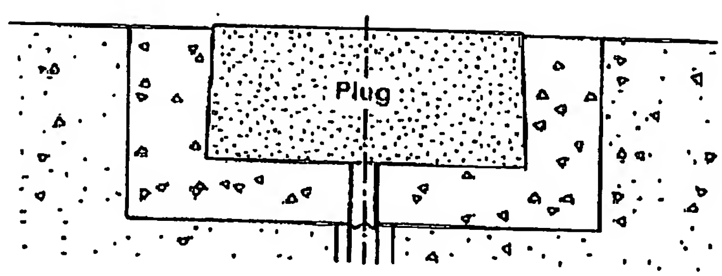

(b)

Figure 3: (a) Water model of porous plug degassing. (b) Schematic illustration showing installation of a refractory porous plug.

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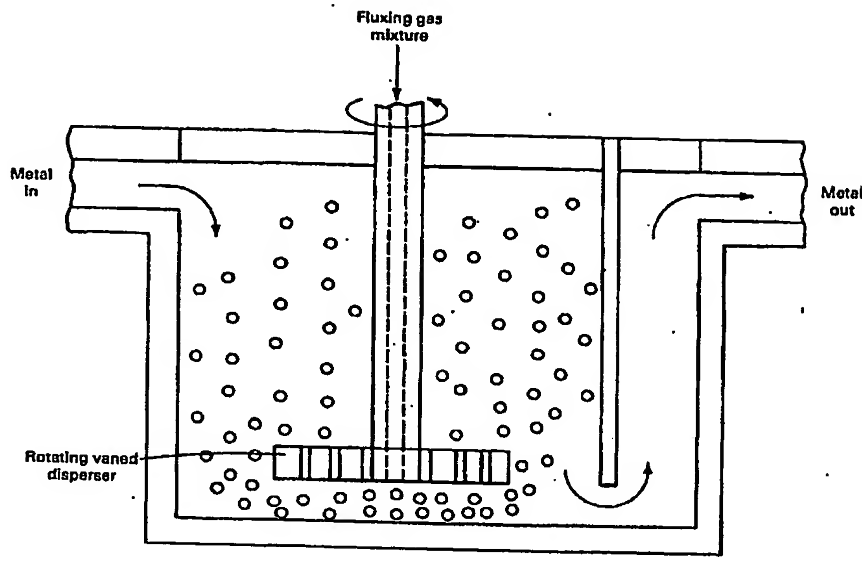

Figure 4: Schematic illustration of an in-line rotary impeller degasser where an inert purging gas is used to remove soluble hydrogen from molten aluminum. The function of the impeller or rotating vane disperser is to chop the gas stream into smaller bubbles in order to increase the contact bubble contact area available for hydrogen transfer.

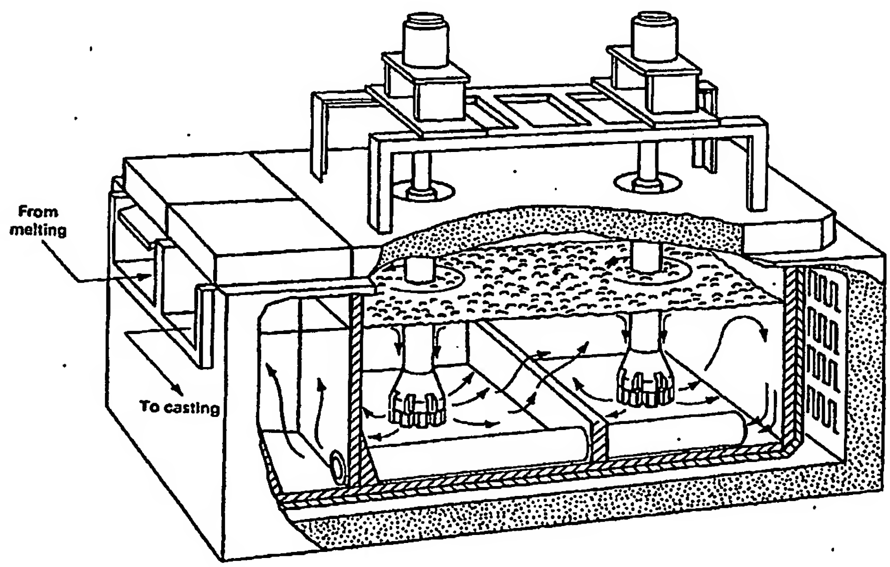

Figure 5: Schematic illustration of an in-line SNIF unit utilizing rotating vane dispersers. For increase hydrogen removal two sequential refining chambers are utilized.

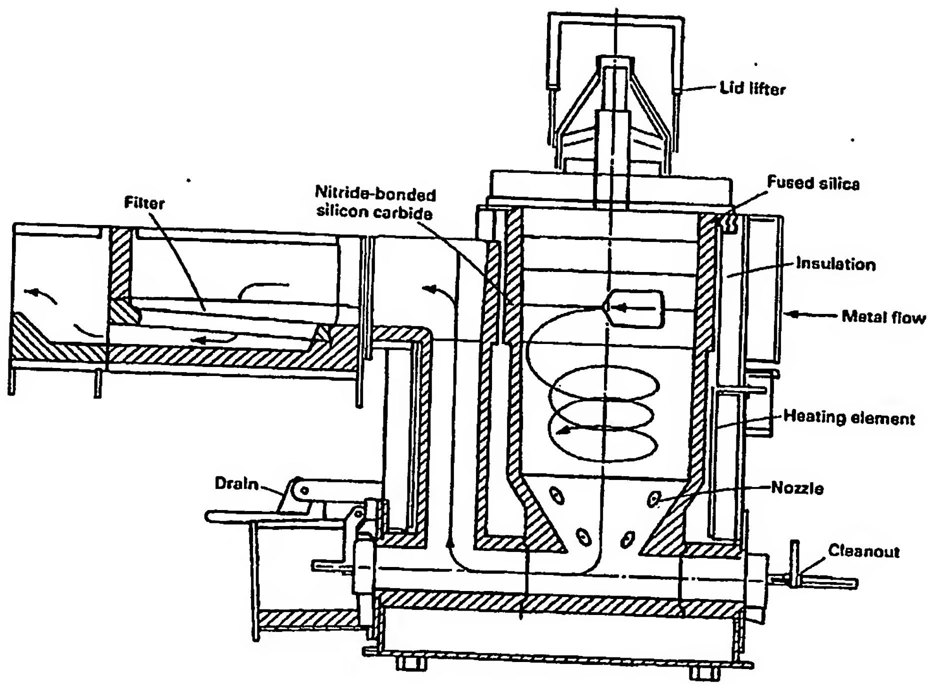

Figure 6: Schematic illustration of a MINT in-line treatment system where the purging gas is introduced as a high-pressure gas through an orifice nozzle.

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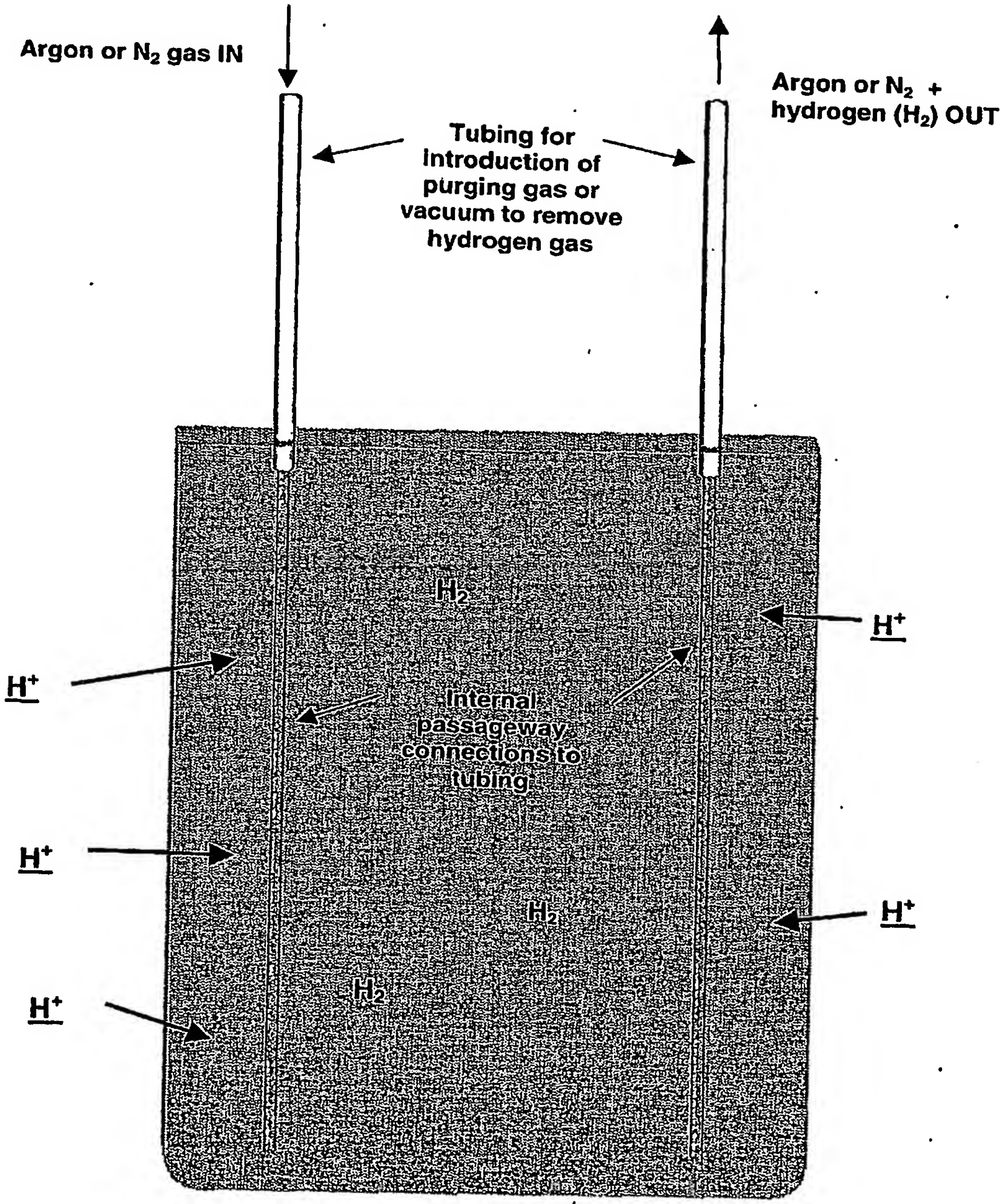

Figure 7: Solid micro-porous plate degassing plate or panel containing hollow internal passages. Purging gas is introduced through one tube and removed by other tube. Other option is to remove the hydrogen gas using a vacuum instead of purge gas.

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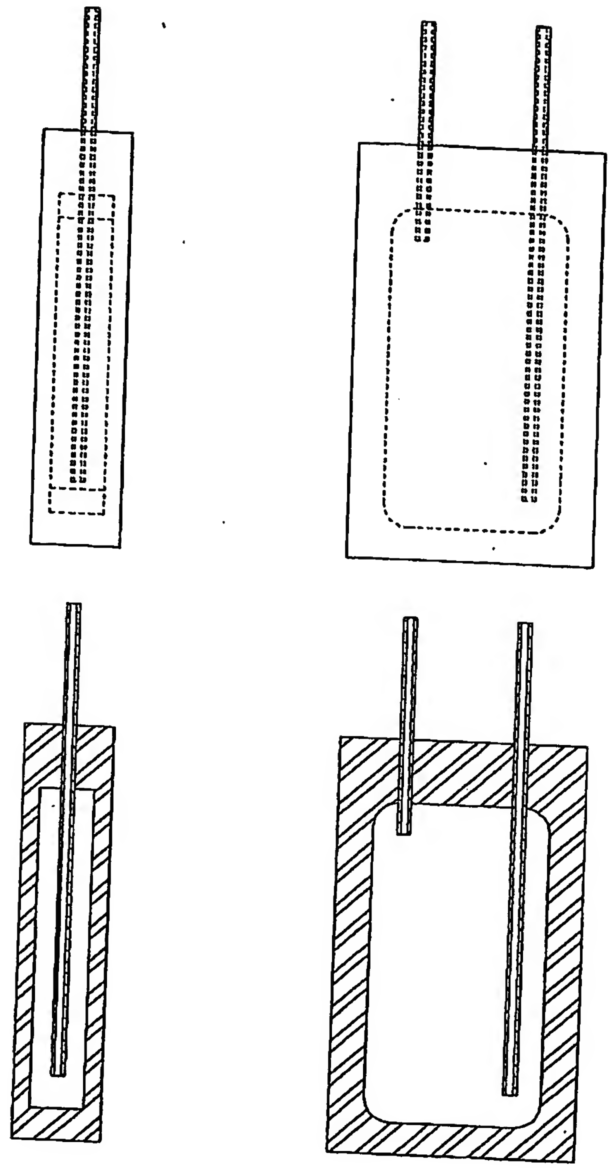

Figure 8: Hollow micro-porous degasser plate containing inlet and outlet tubing for introduction and removal of purge gas. Other option is to remove the hydrogen gas using a vacuum instead of purge gas.

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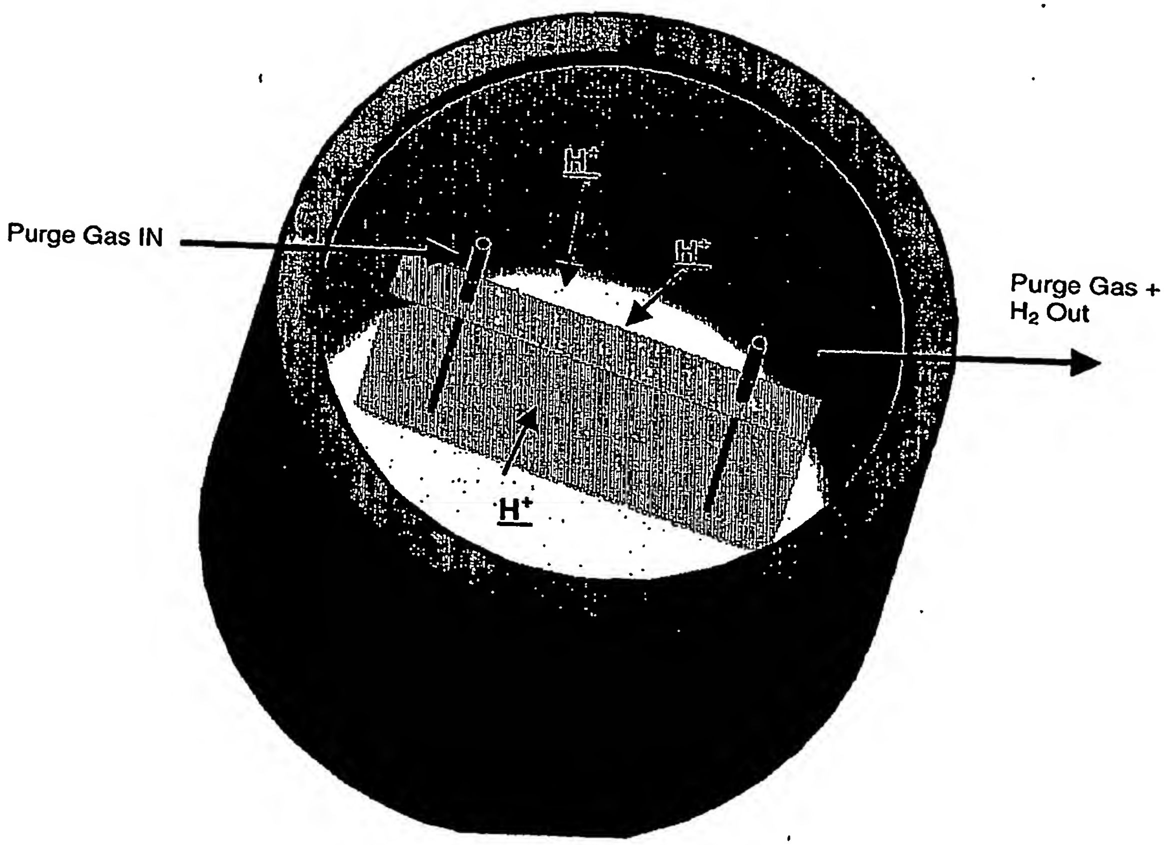

Figure 9:Top illustrate view of micro-porous degassing plate or panel submerged into crucible of molten metal. Note entire panel is submerged into the molten metal

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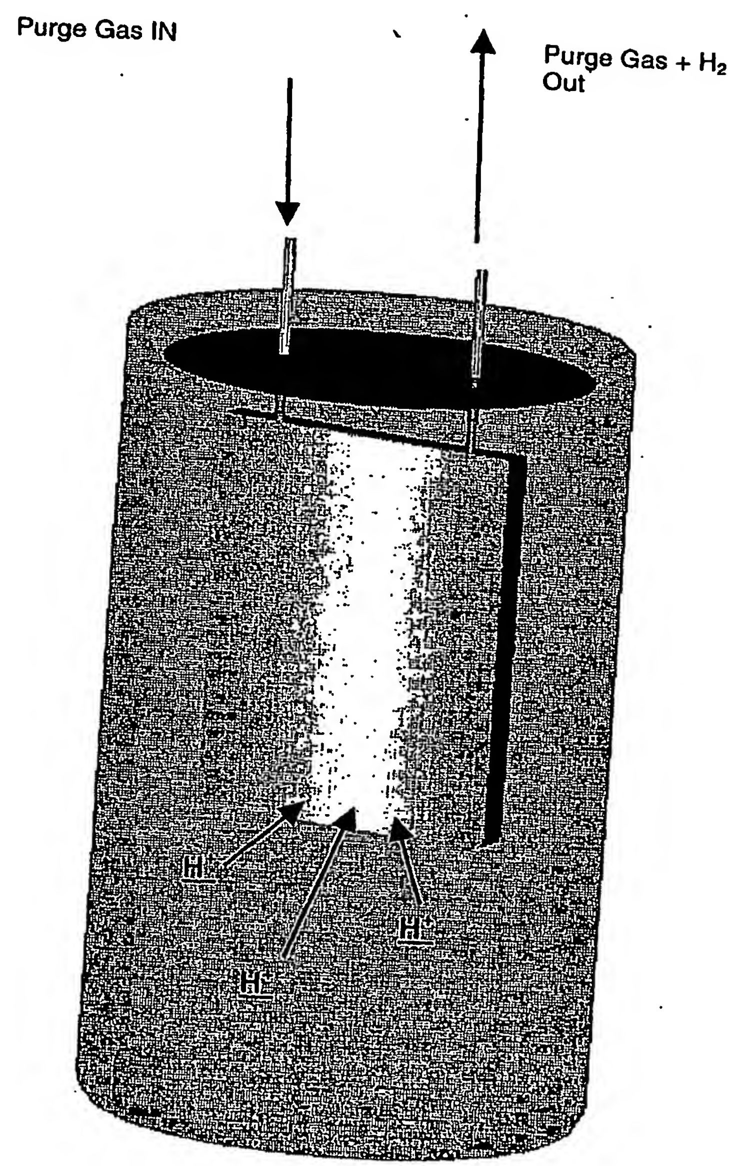

Figure 10:transparent side view of micro-porous degassing plate or panel submerged into crucible of molten metal. Note entire panel is submerged into the molten metal.

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Direction of Metal Flow in Casting Launder

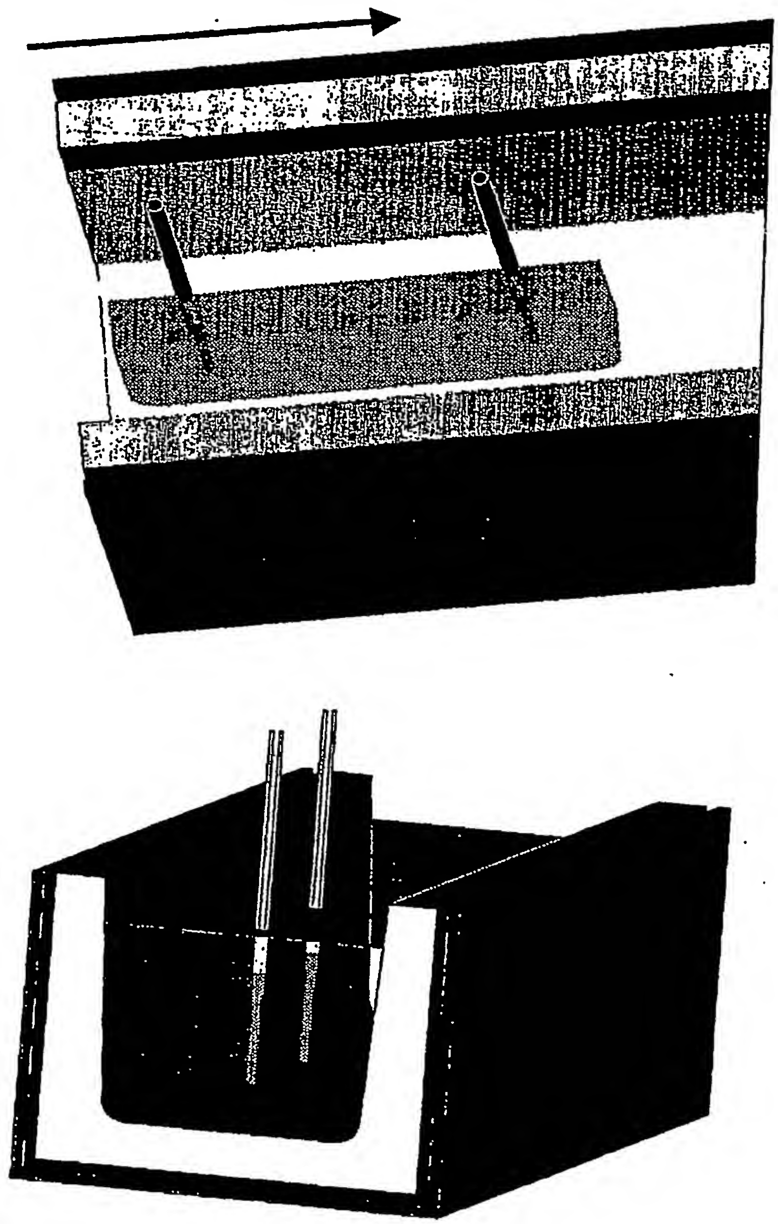

Figure 11: Schematic illustrations of a porous media degasser panel located in a casting launder.

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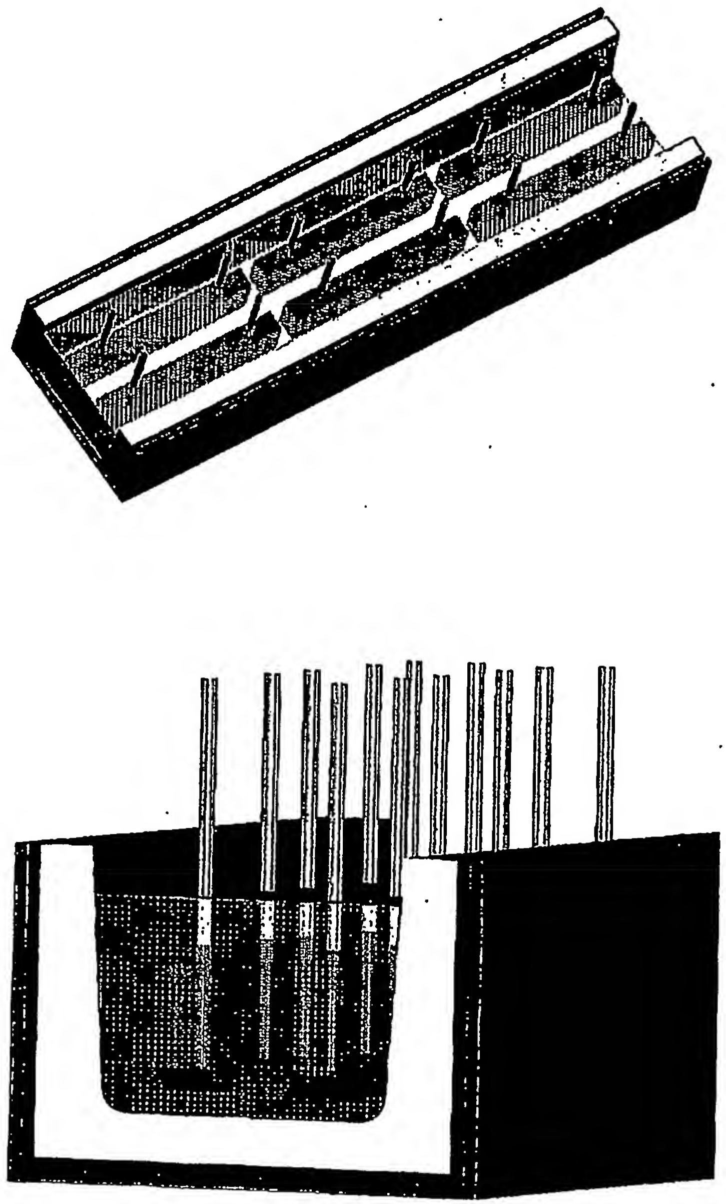

Figure 12: Schematic illustration of a staged series of porous media degasser panels located in a casting launder.

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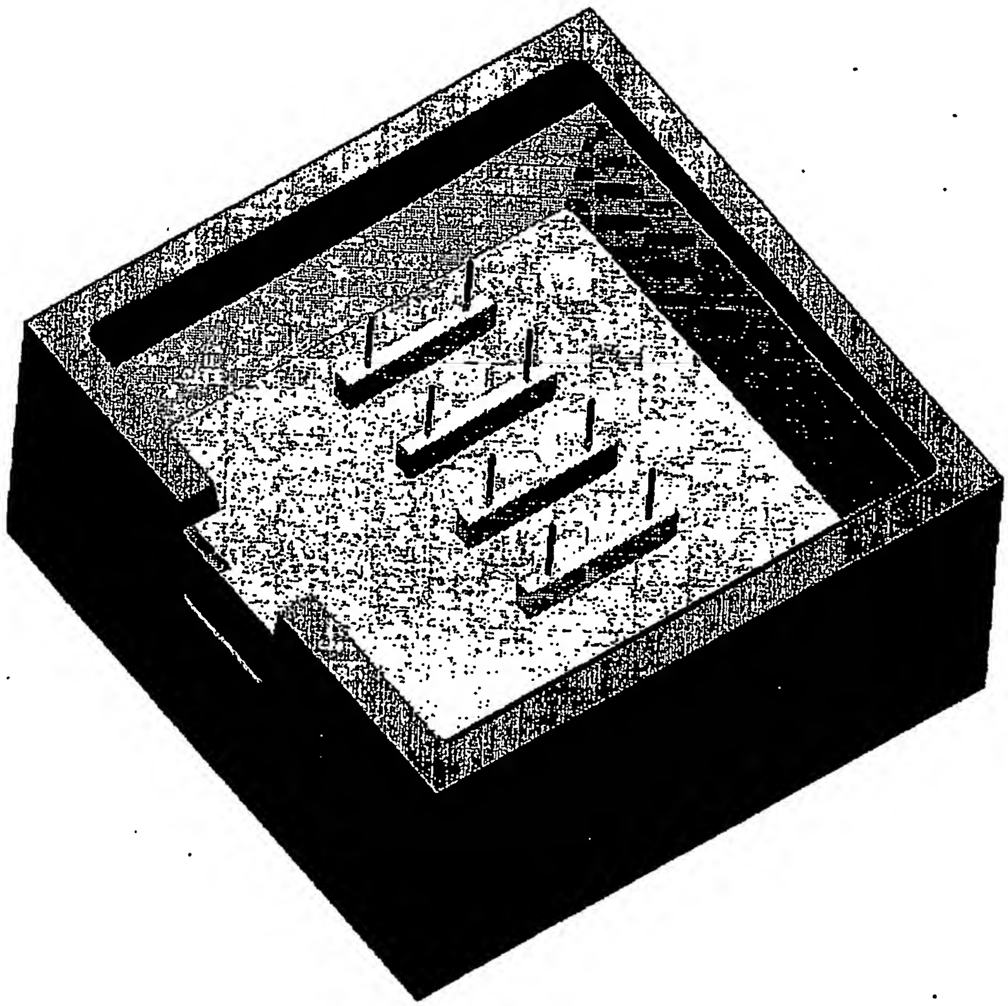

Figure 13: Schematic illustration of porous media degasser panels located in a ceramic foam filter bowl.

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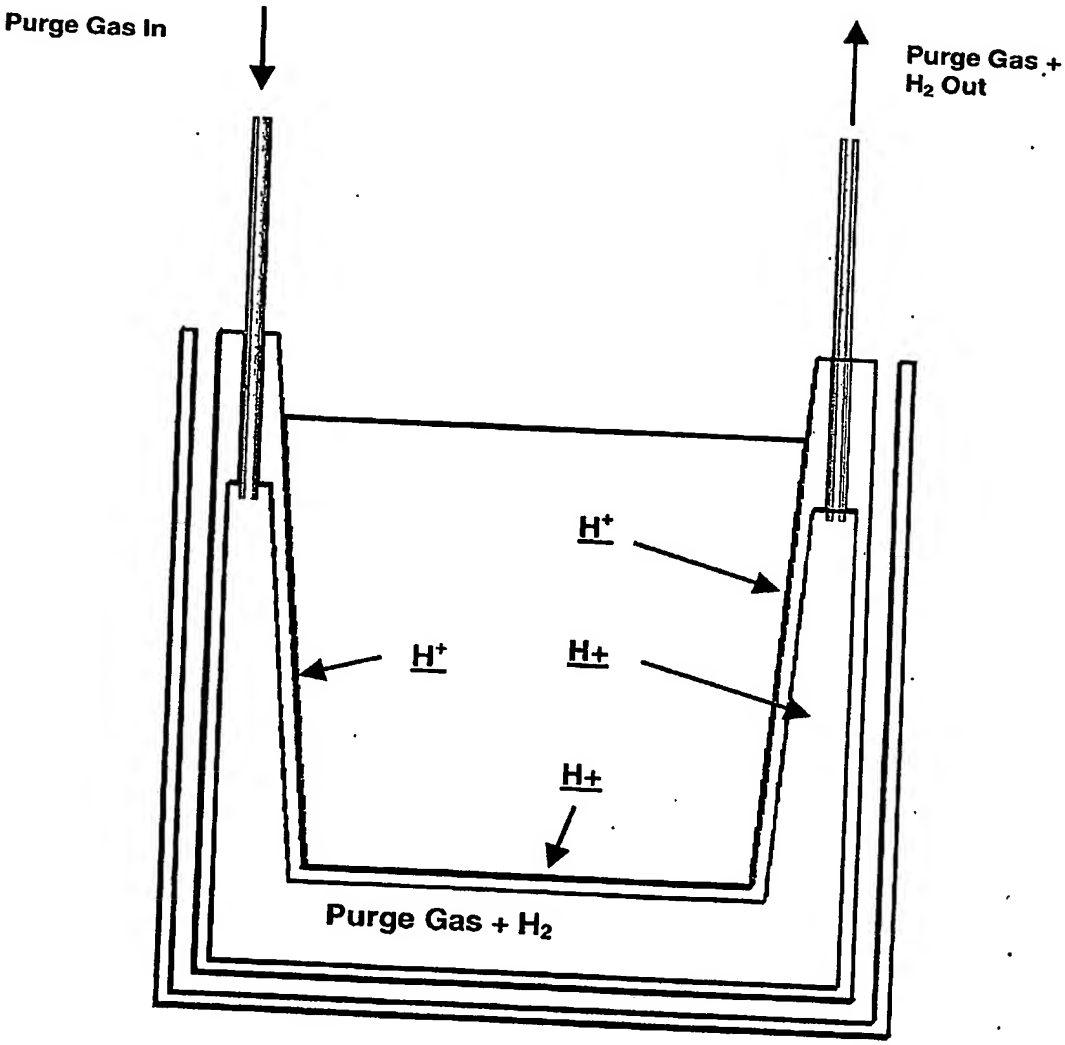

Figure 14: Schematic illustration of a porous media degasser incorporated into casting launder (technical inaccuracies need to be corrected in this illustration).

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